CENTRALISED VENTILATION SYSTEM FOR PREVENTING NOSOCOMIAL TRANSMISSION OF TUBERCULOSIS IN A HOSPITAL ISOLATION WARD

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To my beloved mother and father

Hajah Sarifah Binti Naim

Almarhum Haji Ahmad Shakri Bin Mohd Sekak

To my beloved wife and kids

Nor Hidayati Binti Suhadi

Muhammad Harist Danish Bin Md Rajuna

Dewi Sarah Binti Md Rajuna

Muhammad Hadi Darwish Bin Md Rajuna

Muhammad Hazim Daim Bin Md Rajuna

To my beloved mother and father in law

Hajah Ruminah Binti Dollah Anuar

Almarhum Suhadi Bin Abdul Karim

To my beloved younger sisters and brother

Dewi Rohani Binti Ahmad Shakri

Dewi Sukmawati Binti Ahmad Shakri

Dewi Murni Binti Ahmad Shakri

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ABSTRACT

Centralised ventilation increases indoor air quality for a healthy hospital indoor environment by supplying fresh air from outside to inside the isolation ward and dispose out the stale air. Poor ventilation for isolation wards can increase risks of nosocomial transmission. Thus, the aim of the study is to develop a healthcare setting layout in healthy indoor air environment in order to prevent the nosocomial transmission of Tuberculosis (TB) by centralised mechanical ventilation system for TB isolation ward. This study was conducted at Hospital Sultanah Aminah, Johor Bahru and four stages of qualitative and quantitative research methods were involved. The first step was the interview and questionnaire stage with Healthcare Workers (HCWs) at TB Isolation Wards and Respiratory Specialist Clinic. The second stage was to determine the existing TB isolation ward. The third step was mapping rooms' temperature with imaging thermal infrared. Finally, the design and installation of a mock up room with a centralised ventilation system was evaluated. Thirty nine HCWs answered the five Likert Scale questionnaire survey which identified indoor air environment sustainability factors. Four factors have been selected to choose the most effective room as a mock up. Based on findings, single bedroom was the most effective one based on calculation of air density per patient. The mock up design for selected isolation ward SB2 is 3.000 m length x 2.000 m width x 3.144 m height. Room temperature changes were detected using temperature mapping when the windows set to close and open. A mock up room manages the route of airborne TB transmission and has been designed and installed centralised ventilation system for three persons (1 patient and 2 HCWs) in one time, 15.7 Air Change per Hour (ACH) more than 12 ACH specification requirement, whereby the performance ventilation indicator carbon dioxide does not exceed 1,000 ppm in one time. However, relative humidity and temperature exceeded their acceptable range depending on the surrounding environmental conditions. The study is concerned about the HCWs to protect them by preventing nosocomial TB transmission. The mock up of innovations designed based on environmental and engineering controls has been shown to help in eliminating Building Related Illnesses (BRIs). Thus, it is suggested that this mock up is recommended to function its role not only in Hospital Sultanah Aminah but also in other hospitals.

ABSTRAK

Pengudaraan berpusat meningkatkan kualiti udara dalaman untuk persekitaran dalaman hospital yang sihat dengan membekalkan udara segar dari luar ke dalam wad isolasi dan melupuskan keluar udara yang tidak sihat. Pengudaraan yang kotor bagi wad pengasingan boleh meningkatkan risiko jangkitan yang berlaku di hospital. Oleh itu, tujuan kajian ini adalah untuk membangunkan susun atur penjagaan kesihatan di persekitaran udara dalaman yang sihat untuk mengelakkan jangkitan Batuk Kering (TB) yang diperolehi di hospital dengan sistem pengudaraan mekanikal berpusat bagi wad pengasingan TB. Kajian ini telah dijalankan di Hospital Sultanah Aminah, Johor Bahru dan empat peringkat kaedah penyelidikan kualitatif dan kuantitatif yang terlibat. Langkah pertama adalah peringkat temuduga dan soalselidik dengan pekerja penjagaan kesihatan (HCWs) di Ward Pengasingan TB dan Klinik Pakar Pernafasan. Langkah kedua adalah menentukan wad pengasingan TB yang sedia ada. Langkah ketiga adalah pemetaan suhu bilik dengan pengimejan suhu inframerah. Akhir sekali, telah menilai rekabentuk bilik wad contoh dan pemasangan sistem pengudaraan berpusat. Tiga puluh sembilan HCWs telah menjawab lima *Likert Scale* dalam kajian soalselidik bagi mengenal pasti faktor-faktor kemampanan persekitaran udara dalaman. Empat faktor telah dipilih untuk memilih bilik yang paling berkesan sebagai wad contoh. Berdasarkan penemuan, bilik katil seorang adalah yang paling berkesan berdasarkan pengiraan ketumpatan udara setiap pesakit. Bilik SB2 wad pengasingan TB direkabentuk untuk wad contoh telah dipilih adalah 3.000 m panjang x 2.000 m lebar x 3.144 m tinggi. Perubahan suhu bilik dikesan menggunakan pemetaan suhu apabila tingkap ditetapkan ditutup dan dibuka. Bilik wad contoh menguruskan laluan jangkitan TB bawaan udara telah direkabentuk dan dipasang sistem pengudaraan berpusat untuk tiga orang (1 pesakit dan 2 HCWs) dalam satu masa, 15.7 kadar pertukaran udara sejam (ACH) melebihi 12 ACH keperluan spesifikasi, di mana penunjuk prestasi pengudaraan karbon dioksida tidak melebihi 1,000 ppm dalam satu masa. Walau bagaimanapun, kelembapan relative dan suhu melebihi julat yang boleh diterima kerana ianya bergantung kepada keadaan alam sekitar di sekeliling. Kajian ini mengambil berat tentang HCWs untuk melindungi mereka dari jangkitan TB yang diperolehi di hospital. Inovasi bilik wad contoh yang direkabentuk ini berasaskan kawalan alam sekitar dan kejuruteraan telah dibuktikan boleh membantu menghapuskan Bangunan Berkaitan Penyakit (BRIs). Oleh itu, dicadangkan wad contoh ini untuk berfungsi peranannya bukan sahaja di Hospital Sultanah Aminah tetapi juga disyorkan di hospital-hospital lain.

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LIST OF ABBREVIATIONS

AII	-	Airborne Infection Isolation
AIIR	-	Airborne infection isolation room
BRI		Building-Related Illness
CDC	-	Centers for Disease Control and Prevention
FDA	-	Food and Drug Administration
HAI	-	Healthcare-associated infections
HEPA	-	High efficiency particulate air [filtration]
HICPAC	-	Healthcare Infection Control Practices Advisory Committee
HIV	-	Human immunodeficiency virus
HCW	-	Healthcare worker
HCWS	-	Healthcare Workers
MDRO	-	Multidrug-resistant organism
MDR-GNB	-	Multidrug-resistant gram-negative bacilli
MTB	-	*Bacterium Mycobacterium Tuberculosis*
NIOSH	-	National Institute for Occupational Safety and Health, CDC
NNIS	-	National Nosocomial Infection Surveillance
OSHA	-	Occupational Safety and Health Administration
PPE	-	Personal Protective Equipment
PTB	-	Pulmonary Tuberculosis
PV		Personalized Ventilation
SBS		Sick Building Syndrome
TB	-	Tuberculosis
UVGI	-	Ultraviolet Germicidal Irradiation
WHO	-	World Health Organization

LIST OF SYMBOLS

ACH	-	Air Change rate per Hour
q	-	fresh air flow through the room
Q	-	the volumetric flow rate
Qe	-	the volumetric flow rate of exhaust air
Qs	-	the volumetric flow rate of supply air
V	-	volume of the room
cfm	-	cubic feet per minute

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

About one out of three people worldwide is infected by tuberculosis (TB). In 2008, an estimated number of 9.4 million new cases of TB per year which is equivalent to 139 cases per population of 100 000 globally leads to 2 million deaths per year (World Health Organization, 2013). Most cases of active TB occur in regions of Africa (55%) and Asia (30%), with a small proportions of cases in other regions. Treatment for TB takes at least 6 months in forms of medication while strict adherence to treatment is essential to achieve a cure (Md Rajuna *et. al.*, 2011; Md Rajuna *et. al.*, 2012; World Health Organization, 2013).

One of the factors that causes the spread of infection is incomplete treatment and thus resulting in increment of TB cases. At this time, TB is a major cause of morbidity and mortality (Ministry of Health Malaysia, 2014). As reported by Ministry of Health Malaysia, it states that the tuberculosis communicable disease incidence rate and mortality rate per population of 100 000 are 78.28 and 5.37 respectively (Ministry of Health Malaysia, 2014).

Besides, TB can also infect people at the work place such as hospitals. Individuals with close contact to the TB patients are at high risk for acquiring TB infection or nosocomial infections especially Healthcare workers (HCWs). Nosocomial infection is an infection that is acquired during the course of stay in a hospital, nursing home, or other healthcare facilities. Besides, those people who are

working in a hospital also have a high risk of exposure to the suspended TB in the air space that is shared with other active TB patients (Centers for Disease Control and Prevention, 2009).

Nosocomial infections are transmitted in seven ways by Healthcare Infection Control Practices Advisory Committee (HICPAC), Centers for Disease Control and Prevention as follows: (i) direct transmission via person-to-person contact; (ii) indirect transmission when a patient touches an infected surface or receives treatment with improperly sterilized equipment; (iii) droplet transmission via sneezing and coughing; (iv) airborne transmission relies on air movement to spread microorganisms; (v) common vehicle transmission results from food or water; (vi) vector borne transmission via insect or animal and (vii) the longer a patient is hospitalized and the more severe his condition, the higher the risk of nosocomial infection. (Centers for Disease Control and Prevention 2003; World Health Organization, 2004; Centers for Disease Control and Prevention 2005)

A healthy indoor air environment is essential to provide a healthy work place to HCWs who are involved directly with TB patients. The nosocomial infections need to be prevented by improving the indoor air quality as well as the room setting. Thus, the study of healthcare setting layout in healthy indoor air environment needs to be carried out in order to prevent the nosocomial transmission of TB.

1.2 Statement of the Problem

Tuberculosis is an airborne disease that is caused by long rod-shaped bacteria called *Mycobacterium tuberculosis* (MTB). MTB can survive in the human body without showing any sign and symptom. Airborne transmission occurs when bacteria or viruses travel on dust particles or on small respiratory droplets that may become aerosolized when people sneeze, cough, laugh, or exhale. Airborne can travel on air currents over considerable distances. These droplets are loaded with infectious particles.

TB patients may spread the MTB to the people who they spend time with every day. Those who have been treated with correct drugs for at least 2 weeks, however, are no longer contagious (ATS/CDC 2003). Unlike most infections treated with antibiotics, TB treatment requires at least six months to one year to eliminate MTB organism effectively. An unfinished course of chemotherapy not only leaves the patient still sick and still contagious, but also favours the selection of resistant bacteria resulting in MTB strains with multiple drug resistance. Hence, it is very important for TB patients to comply and complete the full course of antibiotic treatment. Failure to do so will result in recurrent infections as well as multi-drug-resistant tuberculosis (MDR-TB) infection that is harder to treat.

All these indoor environmental quality components come together in an ideal situation to produce an indoor environment that satisfies all occupants and would not increase the risk or severity of the illness. The TB colony transmission is hypothetically associated with multiple regressions and area setting such as opening of windows or doors, placement of windows or doors to allow through-flow of air, ceiling height, floor area and wind speed can be used as a control measure of TB transmission (Md Rajuna *et. al.,* 2011; Md Rajuna *et. al.,* 2012; Escombe *et al*., 2007).

Room setting which is part of a hospital building is also crucial to provide better indoor environment. Room setting takes into account the room facilities, room layout, location of room, interior finishing, air circulation system and accessibility for maintenance purposes that are vital to the design concepts of a room. The relationship between indoor environmental quality and room setting is important especially for the TB Ward.

Thus, healthcare setting layout in healthy indoor air environment should be developed in order to prevent the nosocomial transmission of TB by centralised ventilation system for TB isolation ward.

1.3 Aim of Study

The Aim of the study is to develop healthcare setting layout in healthy indoor air environment in order to prevent the nosocomial transmission of TB by centralised mechanical ventilation system for TB isolation ward.

1.4 Objectives of Study

The objectives of the study are:

(i) To identify the factors affecting the TB airborne transmission in hospital indoor environment;

(ii) To determine the existing TB isolation ward and its layout for mock up study;

(iii) To determine the relationship between isolation ward setting layout and route airborne TB transmission; and

(iv) To propose the design of mechanical ventilation system for TB isolation ward in order to reduce nosocomial transmission by route airborne.

1.5 Scope of Study

The study is conducted in the room of number 2 TB isolation ward, Block PP2, Hospital Sultanah Aminah Johor Bahru (HSAJB), Johor, Malaysia. This selected venue is an unconfined TB isolation ward that is not mixed-use with other airborne disease treatment. Figure 3.2 in Chapter 3 shows the location of selected TB isolation ward and respiratory clinic. The selected respondents for questionnaire categories are healthcare workers who are related to TB isolation ward in HSAJB.

The route of direct, droplet and airborne transmission for nosocomial infections in TB isolation ward is studied and conducted in an unconfined situation which is without air conditioning. The comfort parameters which are temperature

(^{o}C), airflow and relative humidity (RH%). Carbon dioxide (CO_2) are in-situ measurement for ventilation performance indicator.

One room in TB isolation ward has been designed and installed with a mechanical ventilation system for the purpose of providing a healthy indoor air environment to prevent nosocomial transmission of TB.

In this study, the limitations are as follows:

(i) The condition in confined room with no airconditioning and fan switched on.

(ii) Indoor Environment quality parameters for the test in-situ sampling are temperature, humidity and carbon dioxide.

(iii) This study does not make disinfecting bacteria MTB.

(iv) Only one Mock up room with a single bed made with mechanical ventilation system is selected in the TB isolation ward.

1.6 Significance of Study

The finding in this study is important to healthcare workers (HCWs) and TB patients. Preventing the nosocomial transmission of TB by centralised mechanical ventilation system for the TB isolation ward in Hospital Sultanah Aminah Johor Bahru, Johor, Malaysia is the sole purpose of this study. Thus a new healthcare setting layout in healthy indoor air environment is developed as follows:

(i) Prevention person in high risk factors are devided into three categories, Persons who have been recently infected with TB bacteria, Persons with medical conditions that weaken the immune system and HCWs that work at TB Isolation ward.

(ii) Benchmark the design to make a good design based on mock up centralised ventilation system.

(iii) Selected TB isolation room has an optimum single bed layout that follows the requirements and specifications of Malaysia Uniform Building By-Laws 1984.

(iv) Rationale mock up in ventilation system can get data and analysis for future layout.

(v) Potential benefits of ventilation system can manage air flow, Air Change per Hour (ACH) and direction consistent level.

(vi) Overall impact to prevent the nosocomial transmission of TB.

1.7 Novelty of Study

The Novelty of Study can be illustrated as follows:

(i) Prototype to provide the functionality of centralised ventilation system and enables testing of the design.

(ii) Designed can use prototype as single bed isolation room.

(iii) Full-size model of a design, demonstration, evaluation, and promotion.

(iv) Mock up TB Isolation room in order to experience a solution in real life.

(v) The use of environmental and engineering controls solutions for preventing nosocomial transmission of TB in a hospital ward.

(vi) Ventilation improve ACH to the added consistant level.

(vii) Ventilation system provides fresh air force downward to exhaust out the stale air.

(viii) Risk reduction of inhalation of pathogens and the reduction of incidence of TB disease transfer TB airborne with centralised mechanical ventilation system were produced in TB isolation ward.

1.8 Summary of Introduction

This whole chapter outlines the introduction to the problem and justifies the need to conduct this study. It states the aim, objectives, scopes and the adopted methodology. Furthermore it also elaborates the significance of the findings. The output of this study is the design and installation of centralised ventilation system as mock up TB Isolation Room . It provides a useful mean to healthcare workers to work at TB Isolation Ward. Moreover this mock up was developed based on our local working environment. This study hopefully enables the promotion of future isolation healthcare setting.

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